Predictability and Ensemble-Forecast Skill Enhancement Based on the Probability Density Function Estimation

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LONG-TERM GOAL

My long term goal is to make substantial contributios to enhancement of forecast skills in numerial prediction for the oceans and atmosphere, by deepening our knowledge concerning nature of predictability. I place my emphasis on coherent structures, such as costal eddies in the ocean as well as cyclones and squall-lines in the atmosphere.

OBJECTIVES

I wish to address development of theoretical framework by improving and combining currently existing methodologies and techniques. I also wish to adapt new approaches based on dynamical systems theories that have not been used to enhance predictability in the past. My overall approach will involve Eulerian and Lagrangian descriptions of the probablity density funtion evolution, identification and detection of the predictability elements, and understanding of their impacts on the forecast skills. Knowledge obtained by these predictability studies will naturally lead to a design of comprehensive ensemble-forecast systems with improved skills as wellas data-adaptibe observing systems.

APPROACH

As a step towards achieving my research goals, I start from examining individual components which are involved in the theoretical framework. In the first year, I engaged in the following three main projects. First one is analytical development and numerical implementation of a methodology to track distingusihed hyperbolic trajectory (DHT) in the phase space. DHT governs the flow geometry. It therefore plays a key role in understanding predictability of transitional dynamics as a pivot point from one dynamical region to another distinct region in the phase space. This idea concerning DHT can be applied not only to low-dimensional systems, but also higher dimensional systems; for example, it can help identify mechanisms of weather regime transistion in the atmosphere. Furthermore theoretical issues concerning DHT tracking relates closely to Lagrangain and Eulerian estimation of probablity density functions. In the second project, I examined mechanism of Eulerian transfer and defined its relation to Lagrangian transport. This will help constructing optimal observing networks for data assimilation systems which use Eulerian model and Lagrangain observations. In the third project, I applied Lagrangian transport theory to deepen our understanding in squall-line dynamics in the atmopshere

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WORK COMPLETED

DHT was analytically defined, and its relation to hyperbolic stagnation point was proved. The theory was extened to provide an efficient numerical scheme to track a DHT in the velocity field given as data set.

Eulerian transfer was defined theoretically between arbitrary and dynamically selected regions. Its relation to Lagrangain lobe dynamics was proved analytically.

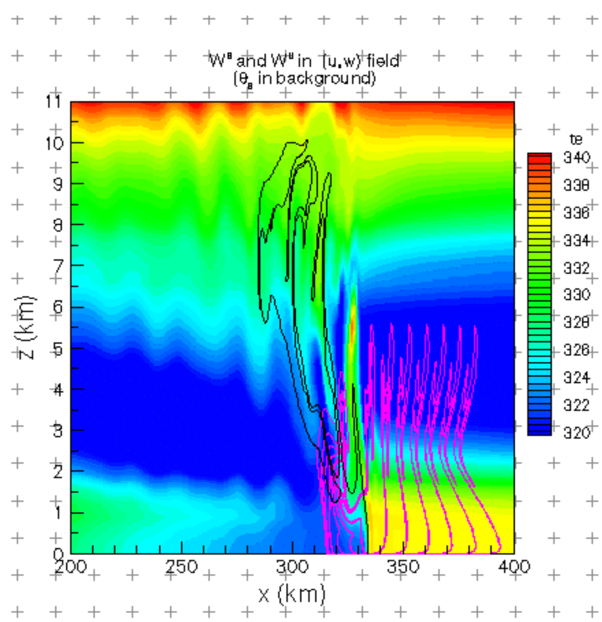
Lagrangain transport technique was applied to 2-D storm simulation (Fovell and Tan, 1998) to provide a geometrical structure of the squall-line system in the atmopshere by interacting invariant manifolds of the flow fields.

RESULTS

DHT is in one-to-one correspondence to hyperbolic stagnation point when they exist for an infinite-time interval. If the data is available only for a finite time, a spectral alalysis can be used to extend the data consistently to an infinite time interval.

Eulerian transfer and Lagrangian transport are related by lobe-like structure, but their transport mechanisms differ essentially. Lagrangain tranport is defined for dynamically selected, deformable regions and boundaries. It measures infinite time transport only. Eulerian transfer, on the other hand, can be defined along any arbitrary boundary for an arbitarary time interval.

In 2-D sqaull line simulation, invariant manifolds structure reveals that air from upstream will stagnate at the bottom of the squall-line, where kinetic enegry is converted into thermodynamic energy. It leads to a strong updraft along the squall-line to pull cold air below to above the squall-line, and finally into higher altitude atmosphere. Furthermore, it was shown that there is no cold air transfer from the downstream of the squall-line due to invariance of the manifold right behind the cold air pool below the squall-line.



Unstable and Stable manifolds of sqaull-line in two-dimensional numerical simulation. Background is equivalent temperature.

IMPACT/APPLICATION

While Lagrangian transport theory offers exact and precise infromation concerning geometry and quantification of transport, its computation is significantly intensive and fine-scale structure may be subject to the presense of stochastic noise. Eulerian transfer theory provides an efficient alternative to compute transfer of mass and phsycial properties, although detail informtaion of the structure will be lost. Because Eulerian transfer can be expressed as a result of interaction between mean and variability, it sheds significant light to enhancement of predicabtility.

TRANSITIONS

DHT tracking methodology has been implemented into Caltech's Lagrangain transport toolkit to compute invariant manifolds from the boundary.

RELATED PROJECTS

1– NASA data assimilation on ocean-atmopshere coupled predictability in collaboration with Michael Ghil (UCLA).

REFERENCES

R. G. Fovell and P.-H. Tan, 1998. The temporal behavior of numerically simulated multicell-type stroms. Part II: The convective cell cycle and cell regenetaion. J. Atmos. Sci., 551-577.

PUBLICATIONS

Two papers in preparation.